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Shrink-swell and cracking of sand-bentonite mixes with EPS inclusion

Contraer-hínchese y el agrietarse de las mezclas de la arena-bentonita con la inclusión de EPS

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ABSTRACT

This paper describes how three reconstituted soils with PI ranging from 22% to 53% were prepared in the laboratory by mixing fine sand and sodium rich bentonite. Recycled EPS beads were subsequently mixed with the Soil-Bentonite (SB) mixes to form Soil With EPS (SWEPS) composites. A series of free swell, shrinkage and cracking tests were performed on these new lightweight geomaterials. Results so far show that the inclusion of EPS beads significantly reduces the severity of volumetric change and cracking of the soils. The proposed technique is thus showing a great promise in sustainable construction through the possible utilization of unwanted materials in earth structures.

RESUMEN

Este papel describe cómo tres tierras reconstituidas con recorrer de PI de 22% a 53% fueron preparadas en el laboratorio mezclando la arena de multa y sodio bentonita rica. Las cuentas recicladas de EPS fueron mezcladas subsiguientemente con la Tierra-bentonita (SB) las combinaciones para formar Tierra Con EPS (SWEPS) compuestos. Una serie de libre se hincha, la merma y agrietar las pruebas fueron realizadas en estos nuevo geomaterials ligero. Los resultados la exposición tan distante que la inclusión de cuentas de EPS reduce apreciablemente la severidad del cambio y agrietar volumétricos de las tierras. El propone la técnica así muestra una gran promesa en la construcción sostenible por la utilización posible de materias no deseadas en estructuras de tierra.

Keywords: EPS, expansive soil, swelling, shrinkage, desiccation, cracking, soil replacement, soil stabilization

1. INTRODUCTION

Today, the principle of sustainable construction is in everyone's mind. As conventional fill materials are becoming more scarce and costly, there are mounting pressures to use recycled/secondary materials to produce commercially viable fill materials. In this case, despite their abundance, expansive soils are generally avoided as they can cause significant structural damage to buildings or pavements.

Generally, expansive soils are clays with high plasticity indices. These soils undergo large volumetric changes with variations in moisture content depending on the moisture content fluctuations. During the wet season rain water imbibes in to the soil resulting in expansion or swelling. On the other hand, in the dry season, moisture evaporation and desiccation decrease the soil volume.

Expanded polystyrene (EPS) is a cellular polymeric material commonly used in packaging. It is a lightweight material with a very low density (13 -20 kg/m^3). In Australia, nearly 7000 tones of EPS is produced per annum for various purposes Being a light-weight and bulky material, waste EPS creates problems associated with disposal and reutilization. While waste EPS have not found a real application in civil engineering, EPS itself has been used in geotechnical applications as blocks or panels since 1960, mainly as a thermal inclusion, and lately as a lightweight fill material for soft soils (Horvath, 1995).

In the present investigation an attempt has been made to investigate the use of recycled Expanded Polystyrene (EPS) beads as a soil replacement and shrinkage reducer for expansive soils. A similar application had been suggested by Miki (1996), where dredged soils were mixed with EPS beads and used as lightweight fill materials.

Artificially prepared expansive soils have been manufactured in the laboratory by mixing fine sand with sodium bentonite of various proportions. Recycled EPS beads have been mixed with these soils and the effects of varying the amount of EPS beads are reported herein.

2. MATERIALS

2.1 Sand

Commercially available fine sand, known as W9 sand, supplied by Riversands Pty Ltd, Brisbane was used. The silica sand is sub-angular and classified as poorly-graded clean medium to fine sand (SP). More than 95 percent of the sand particles pass through #30 sieve (0.420 mm) and less than 5 percent pass #200 sieve (0.074 mm). Figure 1 shows the particle size distribution of the sand used in the present study.

2.2 Sodium Bentonite

Commercially produced sodium-rich bentonite was supplied by Unimin Australia Ltd, Brisbane. The physical properties of the bentonite are shown in Table 1. Bentonite was mixed in various proportions with the sand to replicate the shrinkage and swelling characteristics of expansive soils.

2.3 Recycled EPS Beads

For the present study, waste EPS produce-boxes were collected from the EPS collection centre in Brisbane. The boxes were crushed into granular form in a blender such that 90 percent of the particle sizes fall within the range of 1.2 mm to 9.5 mm (Figures 2 & 3). The gradation of the EPS beads can be varied if so required; however, it has been kept constant in this study.

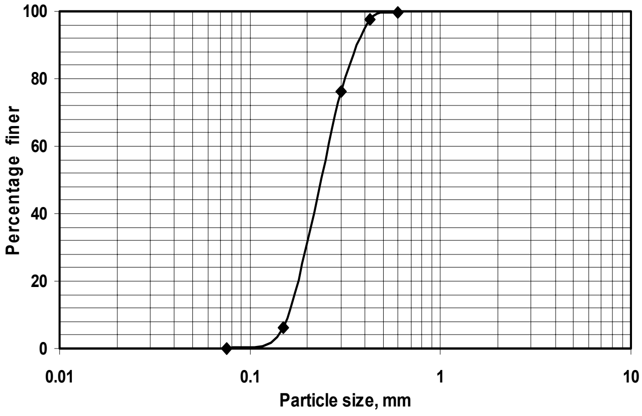

Figure 1. Particle size distribution of sand

Table 1. Properties of sodium bentonite

Trade name	Trubond
Source	Miles, Queensland, Australia
Type	Sodium bentonite
Retained on 75 μm (Wet screen) Passing 2 μm (XRD Analysis)	2% 80%
Bulk density t/m^3	0.9
Liquid limit	400%
Plastic Limit	41 %
Moisture content (as supplied)	11%
Cation exchange capacity	85 meq/ 100 g

3. SAMPLE PREPARATION

From the literature it has been observed that the plasticity index of expansive soils used in various projects around the world ranges from 25% to 50%. To prepare soil mixes with predetermined plasticity indices, de-aired distilled water was added to measured dry masses of sand and bentonite followed by hand mixing at room temperature. After mixing, the material was placed in a sealed container and allowed to equilibrate for 48 hours. Moisture content was determined afterwards and used to calculate the wet soil mass required for compaction to the target dry density (Table 2).

With the bentonite contents selected (16, 24 and 32%), three different artificial clays having intermediate, high and very high plasticity indices (as per BS 5930) were produced (i.e. sand-bentonite mixes SB16, SB24 and SB32).

Figure 2. Crushed recycled EPS (1.2 - 9.5 mm in diameter)

Using the % bentonite and the resulting PI values, the activity of each mix, defined as PI ÷ (% clay), can be calculated (see Table 2) and plotted on the Williams and Donaldson's chart (Figure 4) to predict the expansion potential of the mixes. It is seen that the mixes can be separated into two types, namely high expansion and medium expansion although SB32 may produce a very high expansion.

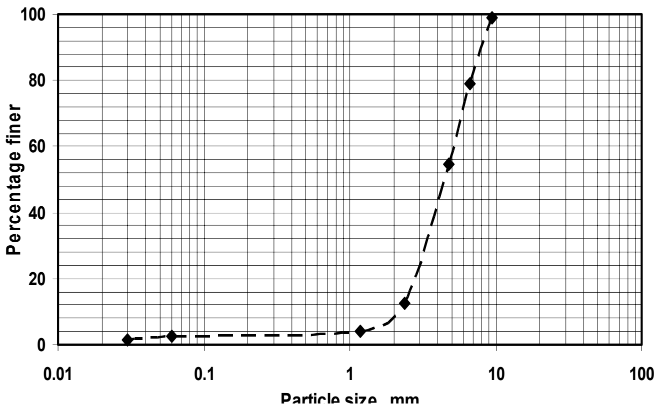

Figure 3. Particle size distribution of the recycled EPS

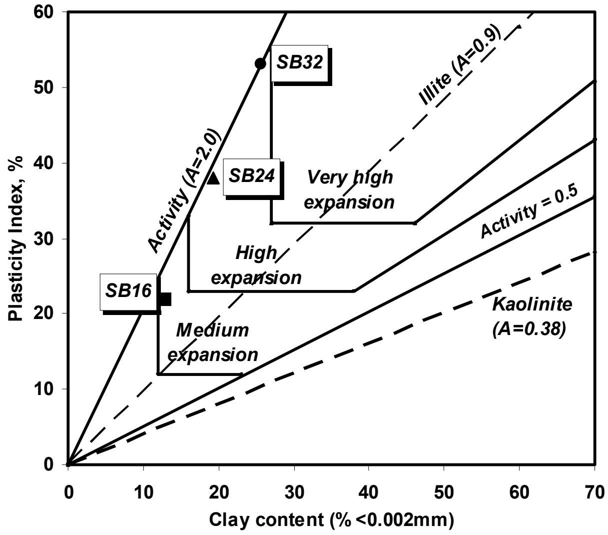

Figure 4. Classification of sand-bentonite mixes using the method proposed by Williams & Donaldson (1980)

An indication to the susceptibility of a soil to shrinkage or swelling due to the variation in moisture content, the swelling potential of a soil can be established in the laboratory by means of one directional ‘free’ swell test.

Figure 5 below shows the predicted swelling potential (axial swelling) based on the soil activity and % bentonite content of each mix. Note that in using this chart (after Seed et al., 1962), the activity has been defined as PI ÷ (% clay - 5). It is seen that the three mixes are expected to produce different swelling potential values.

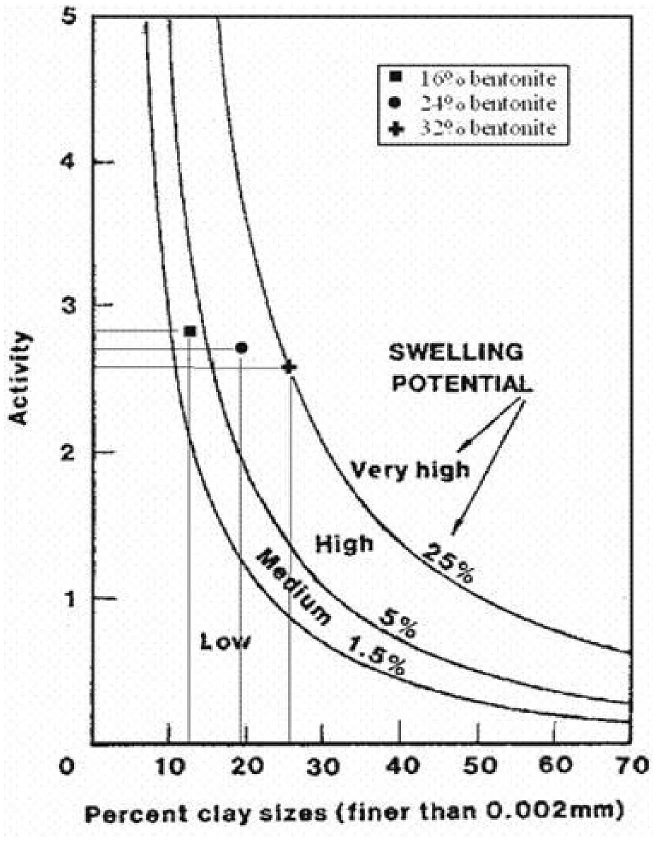

Figure 5. Swelling potential of sand-bentonite mixes as predicted by the chart of Seed et al (1962)

4. COMPACTION CHARACTERISTICS

To study the compaction characteristics, standard (Proctor) compaction tests were performed on a number of SB mixes. With the addition of EPS beads, the density of the resulting composite is much lower than the original soils. This light-weight property may be beneficial for the construction of earth structures, such as embankments and retaining walls.

The EPS beads were added to the moist soil at a certain percentage of the soil’s dry mass. Compaction tests of the soil with EPS (SWEPS) composite were subsequently carried out immediately after mixing the soil and EPS using a bench mixer.

Table 2. Bentonite content and mix properties

Mix	% passing 2μm (by mass of dry sand)	*LL*, %	*PL*, %	*PI*, %	Activity, PI / (% clay)	Activity∗, PI / (% clay – 5)	Max. dry density, t/m^3	Optimum moisture content, %
SB16	12.8	43	21	22	1.72	2.82	1.73	14.0
SB24	19.2	60	22	38	1.98	2.68	1.74	13.0
SB32	25.6	77	24	53	2.07	2.57	1.71	12.5
∗ As suggested by Seed et al. (1962).								

To maintain mix consistency at all moisture contents, care was taken to minimize the effect of segregation while placing and compacting the SWEPS composite. Generally, segregation was not a problem up to an EPS content of 0.9% (although at 0.9%, a slight segregation of beads was observed on the dry side of optimum). Hence, the maximum EPS content was kept at 0.9% by mass.

Compaction curves for mixes of different plasticity values prepared with different percentages of EPS beads are shown in Figure 6. From this figure, it can be observed that with the addition of EPS beads the dry density of the resulting mix varies considerably, but there is no significant variation in the optimum moisture content. This can be attributed to the low bulk density and very low moisture absorbency of the EPS beads. Since the beads are bulk in volume but very low in mass, the mass of the soil-EPS composite is generally controlled by the mass of the soil in the mix. Furthermore, as the moisture is held within the soil particles, the optimum moisture content of the mix is controlled by the optimum moisture content of the soil.

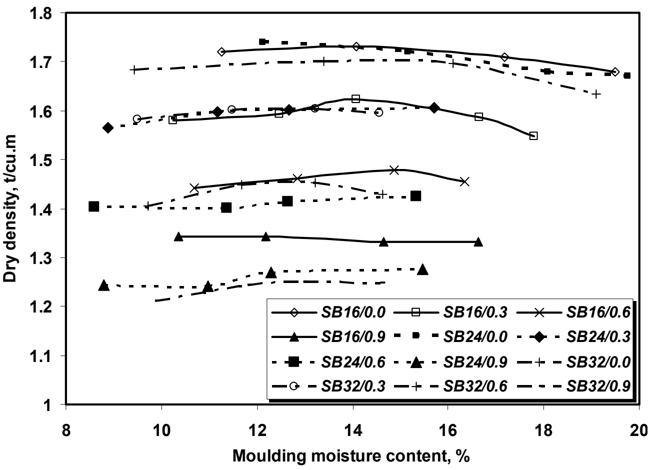

Figure 6. Compaction curves for mixes with bentonite and EPS contents

5. SWELLING POTENTIAL

Using a fixed ring oedometer, the 'free swell' test was performed to determine the swelling potential (as per ASTM D4546-96). The 70 mm diameter specimens were compacted statically to the relevant maximum dry density at the optimum moisture content. To obtain the free swell, a seating load of 6.9 kPa was firstly applied and the specimen was subsequently inundated with distilled water under this pressure. Axial displacements were measured using dial gauges of 0.002 mm precision. Each test was run for at least 2 weeks; thereafter the relationships between swelling and elapsed time were plotted.

Figure 7 shows a typical swell curve from this test indicating that even after 2 weeks, the specimens may still swell although at a much lower rate. Therefore, to fit each experimental curve, the hyperbolic equation was used:

$$\varepsilon_t = t / (a + b\,t) \qquad (1)$$

where ε_t is the free swell at time t, t is the time in minutes from the start of inundation, and a and b are constants determined by the curve fitting procedures.

It is seen from this figure that, at 0% EPS content, the sand-bentonite mixes produce swelling values that are significantly higher than those predicted by the chart of Seed et al (1962) as previously shown in Figure 5.

Furthermore, the effect of EPS inclusion is quite significant, generally reducing the free swell by about 20-50% (higher value for higher EPS content). This is more than would be expected from soil replacement effect alone since the maximum EPS volumetric content was about 25%. This suggests that the EPS also works as a compressible inclusion within the soil.

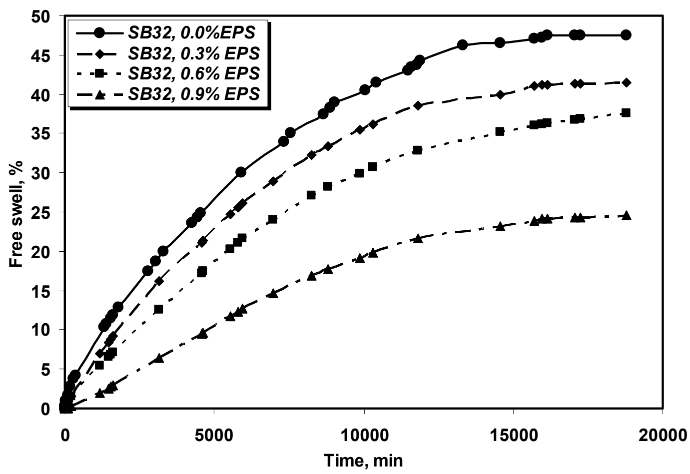

Figure 7. Typical swell curve of the mixes with 32% bentonite content

6. VOLUMETRIC SHRINKAGE

In the present investigation, shrinkage characteristics of the SB mixes were measured by using standard Proctor moulds. This method was earlier proposed by Puppala & Musenda (2000) for finding the effect of fiber reinforcement on the volumetric change of expansive soils. This test is a slight modification of the Texas Department of Transportation Method Tex-107-E.

In this procedure, an oven-dried reconstituted soil was mixed with water at the liquid limit state to form a slurry. The mixture was then poured into the mould and tamped. Subsequently, the specimen in the mould was placed in an oven at 80°C for 48 hours. During this period, the mould was turned upside down and rotated regularly to allow uniform shrinking and drying of the specimen. Thereafter, diameters and heights were measured at three different locations and the averages were noted to calculate the volumetric strain values. The variations in volumetric shrinkage strain with bentonite content and PI values are shown in Figure 8.

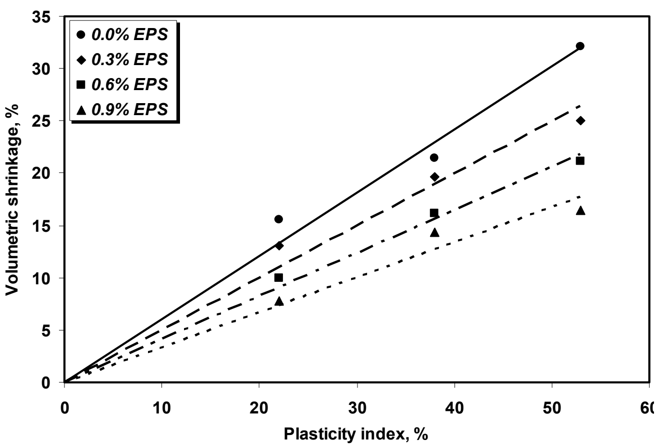

Figure 8. Variation in volumetric shrinkage with PI and EPS content

From this figure, it can be concluded that the addition of EPS beads can considerably reduce the volumetric shrinkage potential of expansive soils.

7. CRACK INTENSITY

Crack intensity is an important factor in applications such as landfill and hydraulic barrier, where proper crack healing upon subsequent wetting can be expected if cracks are reasonably tight and its intensity is kept low.

The intensity of cracks is usually quantified by measuring the area of cracks on the surface of the soil specimen tested. The Crack Intensity Factor (CIF) can be used as a descriptor in quantifying the extent of surficial cracking in a soil mass (Miller et al., 1998 and Yesiller et al., 2000):

$$CIF = A_c / A_t \quad (2)$$

where A_c is the area of cracks and A_t is the area of the drying soil mass.

If a computer aided image analysis program is available, the surficial cracking area can be determined using scanned photographs of the desiccating soils (Miller et al., 1998 and Yesiller et al., 2000). Since the cracks appear darker in the photograph than the uncracked portions of the soil surface, the contrast between the two can be used to calculate the CIF. In the current study, scanned photographs of soil surfaces were analyzed using a MATLAB program to determine the CIF.

Figure 9 shows typical CIF values obtained from 150 mm diameter x 35 mm high specimens. From this figure it is seen that, depending on the PI of the soil, the intensity of cracking can be significantly reduced with the inclusion of recycled EPS beads. Furthermore, it is observed that all the three soil-bentonite mixes display similar linear trend.

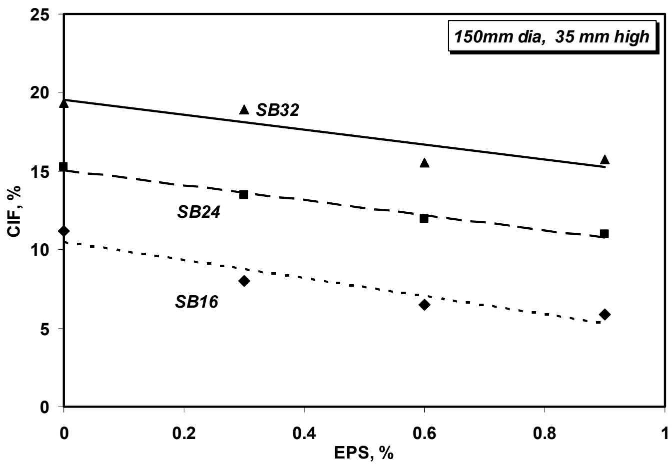

Figure 9. Variation of CIF with EPS content

8. CYCLIC SWELLING

In practice clay soils used may undergo cyclic wetting and drying due to the environmental conditions. Past studies used conventional oedometer ring (commonly 75 mm in diameter, 19 mm in height) for studying the cyclic shrink-swell phenomena in clays. However, in the present case CBR mould was selected since the recycled EPS beads have a maximum size of 9.5 mm.

Test specimens were prepared by static compaction in three equal layers to the maximum Proctor density at the optimum moisture content. The height of the soil specimen was kept at 38 mm (hence diameter/height ratio ≈ 4, similar to that of an oedometer ring).

Specimen wetting was carried out by soaking. The swelling deformation was measured using a dial gauge for at least 2 weeks. In each cycle, after undergoing swelling, the CBR mould containing the specimen was carefully taken out from the water chamber and placed in the oven at 60 °C for three days. Thereafter, the specimen is submerged in water for the next wetting cycle.

Figure 10 shows a typical result from SB24 mix, indicating that EPS inclusion has a significant effect on the cyclic free swelling values of the mixes. While most investigators in the past suggested that, for clays, 4 cycles of wetting and drying would bring the free swelling to an equilibrium value, results from the current study seem to suggest that at least 5 cycles will be needed for testing soils with EPS inclusion. Moreover, it is also seen that the effect of EPS inclusion on the cyclic variation of free swelling is influenced by % EPS and that significantly lower equilibrium free swelling values can be achieved with higher EPS contents.

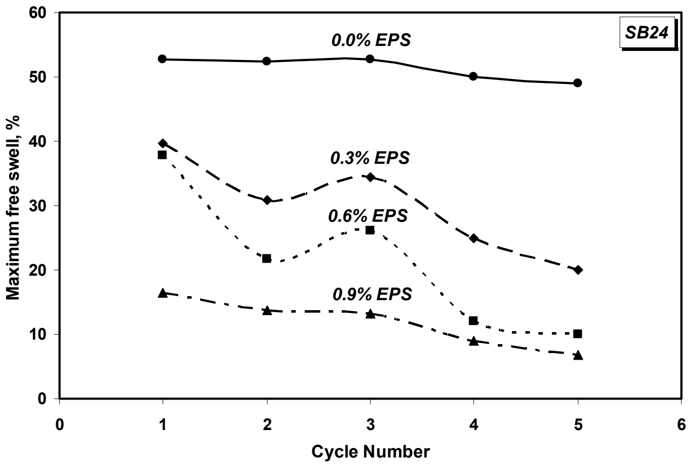

Figure 10. Variation of cyclic swelling with EPS content.

9. CONCLUSIONS

The results of a study on the potential use of recycled expanded polystyrene beads as a soil replacement material to reduce the shrinkage potential of expansive soils have been presented.

Artificially reconstituted soils of different plasticity values were prepared by mixing fine sand and sodium bentonite. It has been found that with the addition of recycled EPS beads, the dry density of the resulting mix varies considerably although there is no significant variation in the optimum moisture content.

The addition of EPS beads into a soil works well as a partial soil replacement. In swelling clays, this can reduce the shrink/swell potential. It was found that the higher the quantity of EPS beads in the soil, the less is the shrinkage potential. A reduction of about 15% in volumetric shrinkage strain can be expected for a soil with a PI of 53 mixed with 0.9% EPS beads by mass.

In addition, it is also shown that with the addition of EPS, the crack intensity and cyclic free swell values can be significantly decreased. The proposed technique is thus showing a great promise in sustainable construction through the possible utilization of unwanted materials in earth structures.

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